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Spray Applications to Citrus: Overview of Factors Influencing Spraying Efficacy and Off-target Deposition[1]

Ed Stover, Dominick Scotto, Chris Wilson, and Masoud Salyani. [2]

Summary

Foliar sprays are routinely applied in commercial citrus production. Low fruit value and concern about potential surface water contamination in the Indian River region have encouraged more careful evaluation of spray practices. Many factors influence spray results, making it challenging to distill research information into practical recommendations. Canopy shape and density are major influences on variable deposition and spray drift. Environmental factors such as temperature, relative humidity, wind speed, and wind direction also greatly influence spray deposition and drift and can change within seconds. In addition the set up of the sprayer interacts significantly with the other factors. This document is intended to provide growers with a better understanding of these interactions, which should help growers optimize spray effectiveness and efficiency while reducing potential off-target effects.

Introduction

Foliar sprays are used to control several important citrus pests. Fresh market citrus production generally requires more intensive pest control than fruit grown for juice, since fruit blemishes reduce market value. The Indian River (IR) area is the primary fresh fruit producing region of Florida, representing 60% (Citrus Administrative Committee, 2001) of the Florida fresh market citrus, but only 22% of Florida citrus acreage (Florida Agricultural Statistics Service, 2001). Since grapefruit represents 59% of fresh citrus shipped from the IR region of Florida (Florida Agricultural Statistics Service, 2001), and is especially susceptible to rind blemishing diseases, it receives a high proportion of all sprays made to IR citrus. For this reason, grapefruit spraying is the primary focus of this paper.

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2. Ed Stover is an Assistant Professor of Horticulture and Citrus Extension Specialist at the Indian River Research and Education Center in Fort Pierce
Dominick Scotto was Production Manager for 20 years at Scotto Groves, Fort Pierce
Chris Wilson is an Assistant Professor of Agroecology at the Indian River Research and Education Center in Fort Pierce
Masoud Salyani is a Professor of Agricultural Engineering at the Citrus Research and Education Center in Lake Alfred

Developments in Foliar Spray Application Methods - 1940-2002

Early Stages

Prior to the 1940s, trees were sprayed using hand-sprayers. Workers sprayed from 20 to 25 gallons per tree and attempted to completely cover all tree surfaces, spraying from both outside and inside of the trees. This method probably provided high uniformity of coverage and best potential pest control given the timings and materials used. However, hand-spraying was a slow, labor-intensive process and routinely exposed applicators to spray materials. By the mid 1940s growers began to experiment with single side boom sprayers that saved time and reduced personnel-exposure, but only applied materials to the tree exterior. Boom sprayers of that period used high pressure nozzles, but lacked fans to aid spray dispersion into the tree canopy. Boom sprayers further evolved into double-sided machines that covered one side of two rows with each pass down the row middle. Similar sprayers using oscillating booms, are still used in some citrus growing areas but only at very high spray volumes (Cunningham and Harden, 1998)

Airblast Sprayers

With the invention of the airblast sprayer in 1937 it became possible to cover acreage more quickly, with fewer people and with even less applicator exposure. Use of these sprayers became routine for Florida citrus in the 1950s. They are now the most common sprayers for commercial citrus in the Indian River area. Most airblast sprayers consist of a tank, a pump, two banks of nozzles which spray materials at a selected volume and pressure, and a fan which forces the spray material outward. Some units have an independent engine that drives the pump and fan.

Spray Volume

Spray volume recommendations for Florida citrus were initially meant to duplicate handgun applications: complete coverage was calculated as 1 gallon per foot of tree height plus 5 (Cromwell, 1975). So a mature 20 ft tree needed 25 gallons of material, resulting in more than 2000 gallons of spray per acre for a typical planting of 85 trees per acre. Since an individual sprayer would hold 200-500 gallons (Cromwell, 1975), it was necessary to refill with water and chemicals several times for each acre sprayed. Partly for this reason, growers and the scientific community began investigating the use of more concentrated sprays. Very low volume spraying (less than 250 gpa)was quickly recognized as problematic, requiring great attention to detail to be effective. As a result, commercial interest waned. However, many growers recognized that spray volume could be reduced by half or more from full dilute rates without seriously compromising pest control (Cromwell, 1975; Griffiths et al., 1950). It was also recognized that reduction in leaf run-off might permit use of less spray material for the same degree of control. Since that time, the trend has been toward ever further spray volume reductions.

Dilute spraying still referred to application rates of 2000 gpa as late as 1975, and 500 gpa was considered a 4X concentrated application (Cromwell, 1975). However, most IR growers now consider 500 gpa a dilute spray. Current application volumes of 250 gpa or less are common for growers using airblast sprayers for fresh grapefruit sprays (Stover et al., 2002a). Very low application volumes (25-35 gpa) are used for some sprays on 14% of IR grapefruit acreage (Stover et al., 2002a) using sprayers such as Curtec™ machines. These sprayers are equipped with stacked cross-flow fans and rotary atomizers and are designed for low volume applications.

Diversity in Current Practices

Various changes in sprayer design have been made in an effort to improve coverage at low to moderate spray volumes. However, modern sprayers rarely achieve the uniform coverage possible with a hand-sprayer. They do, however, provide an acceptable balance between efficacy and efficiency based on existing economic conditions. The wide array of sprayer types, combined with the inherent variability in spray coverage, results in widespread uncertainty about actual differences, benefits, and limitations between spray options. Growers largely approach spraying as an art, adopting new practices according to their risk tolerance and experience to find an acceptable efficiency/efficacy balance. As a result of this *ad-hoc* experimentation, spray practices are now extremely diverse within the IR citrus industry (Stover et al., 2002a).

Factors Influencing Spray Application Efficiency and Efficacy

High variability in spray deposition is evident in almost all published field trials. As described in more detail below, spray deposition is influenced by many factors, making this a difficult area for research. Canopy shape and density are important factors contributing to variable deposition and spray drift. Environmental factors such as temperature, relative humidity, wind speed, and wind direction also greatly influence spray deposition and drift, and substantial changes can occur within seconds. In addition, sprayer features (air volume and velocity, nozzle characteristics and arrangement, and physical profile) can interact significantly with the other factors.

The practical significance of coverage thoroughness varies according to the pesticide used and the pest requiring control. When pests are present, adequate control of mites, scale insects, and most fungal diseases of foliage and fruit will not occur unless a threshold concentration of appropriate pesticide is present on the surfaces of susceptible tissues. Uniform deposition is not as important with pests such as mobile arthropods, since they may contact the pesticide as they move through treated trees. However, it is very important for controlling most fungal diseases of foliage and fruit, since infection can develop when spores are deposited in areas with little fungicide residue. Deposition variability is also an important factor when using pesticides that may cause phytotoxicity, since higher levels of spray deposition may cause localized injury to foliage or fruit. For example, with copper fungicides, levels needed for disease control can produce minor fruit phytotoxicity but risk is increased as copper levels increase (Albrigo et al., 1997).

Interpretation of spray studies is often hampered by wide variability in procedures used. Also, most researchers have focused on measuring spray deposition since this is more objective and less difficult than measuring spray coverage, even though coverage is probably more important for commercial production. In addition, few experiments assess actual pest control or include deposition data for the upper canopy of tall trees. These factors make it difficult to improve commercial spray practices based on experimental results.

Combined, these factors result in widespread grower perception that spray research information often does not help them make useful decisions. The following sections focus on the factors and interactions that affect spray deposition efficiency and efficacy. These factors are grouped into four categories: 1) canopy geometry and density, 2) weather (environmental conditions), 3) mechanical set-up of the sprayer, and 4) interactions between these factors. This information should provide a useful background for anyone interested in optimizing orchard spraying.

Canopy Geometry and Density

A tree crop is a complex target in which thickness, shape, and foliage density varies. Variability in deposition within the tree canopy appears to increase as tree canopy density increases. Since current sprayers only apply materials from the trees exterior, there is almost always more deposition on the exterior foliage, with less total deposition in the interior and top of the tree canopy regardless of spray volume (e.g. Salyani and Hoffmann, 1996). Citrus trees generally have greater canopy density than most other tree crops, making uniform coverage especially difficult (Spray Drift Task Force, 1997). Shielding by neighboring leaves and fruits results in some fruit surfaces with poor deposition (Albrigo et al., 1997) and can cause very different deposition between neighboring leaves. The high outer canopy density common to grapefruit typically blocks a large proportion of the spray before reaching the tree interior. In addition, high outer canopy density may deflect considerable amounts of spray over trees, increasing drift compared with similar sized trees of other tree crops (Spray Drift Task Force, 1997).

Sprayer air velocity and material distribution declines as spray enters the tree canopy, especially in the upper interior of the tree. Use of high volume sprays from numerous directions, as with the original citrus hand-gun applications, permitted uniform application by covering all surfaces and allowing excess material to fall from the tree. However, the inefficiencies from this approach are not economically or environmentally acceptable, making mechanized application the only viable option for commercial citrus production in Florida.

Weather

Weather conditions such as wind speed and direction, relative humidity, and temperature can markedly affect both tree and off-target deposition during a spray application. Research indicates a strong interaction between these weather factors and droplet size.

Wind

Wind speed is probably the single most important environmental factor affecting spraying and studies assessing spray technology are usually conducted under low-wind conditions. Laboratory studies indicate that wind speed as low as 3-5 mph substantially deflected droplets <200 µm in diameter (Fig.1). Smaller droplets were deflected more than larger droplets.

Channeling and blocking of wind within the grove and by surrounding structures make wind speed and direction highly irregular in the field. Wind effects on deposition are greatest when wind is parallel to tree rows (perpendicular to the spray stream). Some publications speculate that wind perpendicular to tree rows may have less effect on spray deposition except at the very tops of trees where turbulent air disrupts spray movement, especially for mature groves with minimal space between trees (Spray Drift Task Force, 1997). In a recent survey, IR citrus producers reported no direct monitoring of wind conditions when spraying (Stover et al., 2002a). Growers most commonly relied on visual evidence that the sprays were not reaching the trees to decide whether or not to spray. This practice may be misleading, since the more visible, larger droplets are less affected by wind, and may readily reach target surfaces. However, the smaller, less visible droplets may be carried away with the wind, never reaching their intended targets. Wind speed during spray application can also play an important role in pollution resulting from off-site drift.

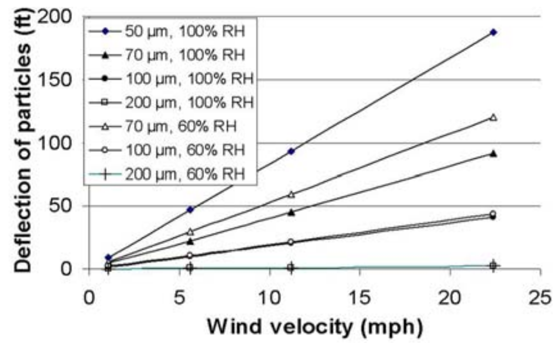

Figure 1. Effect of windspeed on spray droplet deflection. Droplets discharged at 44 mph (20 m/s) at a target 1.6 ft (0.5m) below at 20 C. Adapted from Zhu et al. (1994).

Temperature and Humidity

Along with wind speed and direction, temperature and relative humidity affect the likelihood of smaller droplets impinging on the target. At a relatively high temperature and low humidity, significant evaporation can occur before some spray droplets reach the adjoining tree. This is especially important with droplets smaller than 70 microns. At 80% humidity, 86°F and wind speeds of 11.2 mph any 50 µm or smaller droplet will evaporate before it travels 1.6 ft (Fig. 1) (Zhu et al., 1994). Even larger droplets evaporate to some extent as the temperature increases or the humidity decreases.

Spray Machine Design and Set-up

A central goal of sprayer design is to efficiently and effectively deliver materials with reasonable uniformity over tree surfaces. Most orchard sprays in the U.S. are applied using some type of air-assisted tractor-drawn sprayer. Various modifications to these sprayers have been made with the goal of increasing application efficiency and/or effectiveness of pest control. The following sections describe each sprayer type and equipment modifications commonly employed for improving spray coverage.

Airblast Sprayers

Airblast sprayers are by far the most common sprayer type used by IR citrus growers (Stover et al., 2002a) and for most other tree fruit industries. The majority of sprayers currently in use are fundamentally unchanged since the first airblast machines were released. Most have a single axial fan that is used for blowing spray materials at target trees. The spray materials are delivered to the air currents through a radial array of spray nozzles. Airblast sprayers may be engine-driven or tractor PTO-powered.

The sprayers are designed to accommodate 7-40 nozzles per side. Nozzles with different output can be selected for different positions along the manifold, which permits tailoring the spray pattern to individual needs. Sprayer output can be adjusted by selecting nozzle disc and core combinations, changing the pressure, or by selectively shutting off nozzles. While most IR citrus growers use airblast machines for spray volumes of 125 gpa or higher, they can be nozzled to deliver much lower volumes, while providing reasonable spray coverage (Whitney and Salyani, 1991). However, small diameter nozzles clog frequently when using particulate spray materials and many unfiltered water supplies. These factors establish a practical lower limit to output for each individual operation.

Application rate per unit area is determined by the output per minute and sprayer ground speed. Since fan rpm is controlled by a separate engine for the engine–driven sprayer, application rate can easily be adjusted through a continuous range of tractor speeds. However, a PTO machine must use the rpm designated for sprayer operation, and tractor speed is a function of gear selection at that rpm.

Airblast sprayers vary widely in the air velocity and volume displaced per minute. While these factors are determined by sprayer design and set-up, they are best understood by considering their interaction with tree characteristics, and are discussed below.

Low-Volume Sprayers

The second type of sprayer in common usage for IR citrus is specifically engineered for applications at low volumes (i.e 20-50 gpa). Often called concentrate sprayers, machines such as the Curtec™ and Agtec™, are also air-assist sprayers. Unlike airblast sprayers, Agtec™ and similar machines use squirrel cage fans to generate high-velocity air for air-shear nozzles, while Curtec™ uses 6-8 individual cross-flow fans with rotary atomizers stacked in a tower. The fan can be angled to fit the tree geometry. Manufacturers recommend spray application at ground speeds as high as 3 mph vs. the standard 1-2 mph for most airblast applications. The higher ground speeds during spraying and reduced fill-time (compared to airblast sprayers operating at higher gpa), greatly increases the potential acreage sprayed per hour (Stover et al., 2002b), and may reduce the number of sprayers needed to effectively manage the same amount of acreage. However, there is concern that these low volume machines may not provide adequate coverage in larger, dense trees (Whitney and Salyani, 1991), or provide the complete coverage recommended when using oil sprays for pests like snow scale.

Interactions Between Sprayer Parameters, Tree Characteristics, and Weather Conditions

These factors may significantly interact, influencing spray efficacy and efficiency. Important sprayer parameters involved in these interactions include: sprayer air velocity and displacement, droplet size, and height, and distribution of spray nozzles.

Sprayer Air Velocity and Tree Characteristics

An understanding of spray stream and canopy interactions is essential for understanding the spray deposition process. Air volume and speed affect the ability of droplets to land on leaves or fruit, and the ability of large droplets to reach the target before falling to the ground. Even when unobstructed, air velocity of the spray stream declines rapidly over short distances (Fig. 2; Fox et al., 1983). Disruption of air movement by the canopy further reduces air velocity. Pressure builds up in front of leaves, branches and fruit as air flows through and around the tree, resulting in a pressure boundary layer. As a result, smaller droplets with less energy are deflected away from leaves and fruit. In contrast, larger droplets possess more energy and are less easily deflected from their original trajectory. However, the higher percentage of the larger droplets impacting the outside foliage, rather than being deflected around the leaves, often results in more runoff from the foliage. Slower application speeds using the same spray volume may result in more even interior spray deposition (Salyani, 1995). There are some reports that excessive sprayer wind velocity can decrease deposition, especially when the target plants have a narrow canopy or low canopy density.

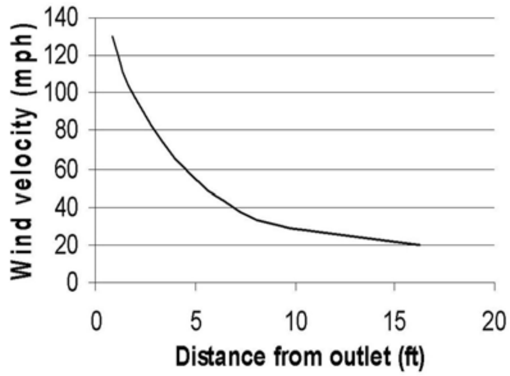

Figure 2. Effect of distance from outlet on air velocity from a fan jet. Adapted from Fox et al. (1983).

Sprayer Air Displacement

Sprayer air volume, usually described in cubic feet per minute (cfm), affects the sprayers ability to replace the air in the tree canopy with spray-laden air. It has been widely accepted for the past 50 years that successful tree coverage requires that the volume of air issuing from the sprayer be equal or greater than the volume of air contained within the tree row. This idea was expressed in the recommendation that travel speed should not exceed the value which allows "complete air displacement" within the tree row, as determined by the sprayer fan air capacity and the number of seconds in which an individual tree is sprayed. Since the sprayer travels down each side of the tree row, complete displacement is approximated when the air output from one side of the sprayer equals half of the tree row volume (Table 2). Agricultural engineers now consider this conservative, since additional air is entrained with the spray stream to push aside the volume in the tree canopy. However, there clearly is some level where adequate interior coverage will not be possible because of excessive ground speed. This may contribute to the observation by Salyani and Whitney (1991) that uniformity of deposition is highest at lower ground speeds, and decreases as speed increases (especially towards the interior of the tree), when they compared ground speeds ranging from 1-4mph with the same spray delivery volume. Also melanose control on interior grapefruit was reduced at partial vs. complete air displacement in an Indian River study (Stover and Salvatore, 2002). It is worth noting that most published airblast trials are conducted using conditions that approximate "complete air displacement" (Stover calculations on published data).

Sprayer Modifications to Enhance Coverage

Sprayer design can greatly influence coverage and potentially influence pest control. Good spray coverage in the upper interior of a tall tree is the greatest challenge in citrus pest control. A typical airblast sprayer has its highest nozzles at 5 to 8 feet above the ground, while the height of a mature grapefruit tree may exceed 20 feet. Spray from the upper nozzles must travel some distance to reach the upper interior of such a tree, in addition to having to pass through several layers of leaves in the upper tree exterior. The density of spray droplets per cubic foot of airstream decreases greatly with the distance from the nozzle to the target. This is the basis for the recommendation that 2/3 of the total spray material be directed to the upper half of the tree, when using an airblast sprayer with conventional radial delivery. In the past this was achieved by placing larger nozzles in the top half of the sprayer, but in most modern sprayers, the same effect is achieved by designs that position nozzles closer together in the upper half of the sprayer manifold.

Adjusting the sprayer configuration to better match the canopy shape can provide more even spray distribution. One low volume study which utilized nine different sprayer models demonstrated how difficult it is for a low profile machine to place material at the top of a tree due to canopy geometry (Carman and Jeppson, 1974). Some sprayer manufacturers have either placed the nozzles on towers or directed the spray through a tower volute to bring the air-blast closer to the top of the tree for more even deposition. Comparison of sprayers with and without towers has shown increased deposition in the upper portion of the tree with towers, although the towers must be properly aimed. Recommendations for California growers have included the suggestion that no tree over 11 ft. be sprayed without a tower (University of California, 1984). The low volume Curtec™ sprayers utilize towers to enhance spray delivery.

Another common modification of sprayers has been the inclusion of oscillating nozzle banks or airstreams. Use of oscillators is based on the idea that fluctuations in airstream direction will more effectively move aside leaves and increase spray penetration into the tree interior and coverage on both sides of leaves. Data on the value of oscillation are conflicting. Salyani and Whitney (1991) reported no increase in coverage or deposition using oscillators; while Brooks (1969) suggested a benefit for dilute sprays but minimal value for concentrate sprays. Some growers have a strong preference for use of oscillation in trees with dense foliage.

Droplet Size and Interactions

Spray droplet size distribution is a crucial factor influencing many aspects of both deposition on-tree and off-target spray losses. Sprayer design and configuration influence the distribution of droplet sizes, which is further modified by environmental conditions during the application. Additionally, droplet size in the spray stream affects interactions with the tree canopy influencing deposition and distribution of spray chemicals.

Disc-core nozzles currently used for airblast spray machines generate a wide range of droplet sizes while rotary atomizers used with low-volume Curtec™ produce a much narrower range and generally smaller maximum droplet sizes. On conventional airblast sprayers, smaller droplets are generally generated by smaller nozzles, and range of droplet sizes can only be effectively reduced by lowering the maximum droplet diameter. Droplet sizes are conventionally indicated by their diameter in micrometers (µm, also called microns). A useful statistical parameter used to describe sprayer output is the volume median diameter (VMD) which is defined as the droplet diameter at which half of the total spray volume is comprised of droplets below the VMD. The advantages and disadvantages of small vs. large droplet sizes illustrate the complexity associated with optimization of spray applications.

In general, larger droplets have more kinetic energy and therefore have a more sustained trajectory toward the target, with less risk of being diverted by wind, evaporating to prevent deposition, or being unable to impinge on tree surfaces by penetrating the boundary layer. However, others report that droplet sizes of 300 µm or less have greatest retention, since larger droplets are more likely to roll off of the foliage and fruit, contributing to runoff. Total spray retention is greater with smaller vs. larger droplets. This is true even when spraying to drip (i.e. 100 µm drops providing 33% greater spray retention than 200 µm drops).

For practical considerations with currently available sprayers, it is not possible to completely separate the issues of droplet size and spray volume per acre. Nozzles producing small droplets also produce less volume per unit time. With the limited spaces for nozzle placement on most sprayers and a fairly narrow range of reasonable tractor speeds, smaller droplet sizes translate into lower spray volumes per acre. Use of larger droplets also requires more spray volume to achieve the same coverage of the target surface area because of the greater volume per surface area in large droplets. In contrast, lower volumes are required for good coverage when smaller droplets are used.

When different spray volumes were applied to mature citrus, larger droplets associated with higher volumes are more likely to coalesce and run-off of outer foliage, while a higher proportion of smaller droplets were retained on exterior surfaces and were distributed less consistently throughout the canopy. These two properties contribute to greater variability of deposition between exterior and interior surfaces with low volume, fine droplet applications. Smaller droplet sizes also increase drift potential regardless of spray volume. In practice, both environmentally and economically, one must weigh the relative importance of runoff from larger droplets vs. greater deflection of smaller droplets.

Selection of an appropriate array of nozzles may provide the best compromise for use in airblast sprayers. Greatest deposition on leaves close to the sprayer occurred with spray comprised primarily of moderately small droplets (270-340 µm), while spray including much larger droplets (610-720 µm) provided highest deposition on the most distant targets. The benefit of large droplets on distant targets may be even greater in the field, since droplet size may decrease by 25-50% before reaching the tops of trees. This suggests that optimal field configuration may involve use of smaller nozzle diameters in mid to low manifold positions, with larger nozzles in the upper positions.

Factors Influencing Drift and Off-target Environmental Contamination

Off-target deposition of spray material is both an economic loss to the grower and a potential environmental problem. Environmental issues related to spraying in the IR area include off-target deposition due to drift and to foliar runoff. These are considered below.

Drift

Drift refers to spray material that is carried away aerially by sprayer generated air movement or natural wind, and is not deposited on the intended target. Evaluating these losses is difficult since accurate studies are expensive and variability is high. Actual measurement of total on-target deposition is prohibitively difficult, so researchers typically measure ground deposition and drift to develop estimates. Problems associated with drift measurement are demonstrated by a study in mature grapefruit where substantial spray material was recovered even at the maximum sampled height (39 feet) (Spray Drift Task Force, 1997) making total drift assessment virtually impossible. Ideally samples would be collected to heights and distances from the spray source where the tracer becomes non-detectable.

When considering past research regarding spray drift measurement, it is important to realize the limitations of those studies. Differences in methodology, canopy characteristics, wind and other weather factors, and planting density may all significantly affect the results of drift studies.

Results from studies measuring off-target deposition share several common conclusions. Smaller droplets are more prone to drift, and the percentage of material drifting off-site increases with both wind speed and decreased droplet size, and ground deposits typically are greatest within 50 feet of the sprayer. This occurs because the larger droplets fall out within a short distance, due to gravity and air resistance, whereas smaller droplets tend to travel for extended distances. When samples are collected during spraying, ground deposition per unit air volume declines rapidly with the distance from the sprayer, however, airborne material typically exceeds ground deposits about 200 feet from the spray course. This airborne material can travel great distances before deposition.

Identification of a drift-prone droplet size threshold or critical wind speed is attractive but somewhat arbitrary. Some researchers have suggested 100µm as the threshold for droplets with high drift potential, others have suggested 141µm (Spray Drift Task Force, 1997), while still others indicate that droplets under 200µm are very prone to drift when wind speed exceeds 5 mph (Zhu et al., 1994). Sprayers built specifically for low volume applications, such as Curtec™ and Agtec™, generally produce most droplets well within the size range specified for high drift potential. However, even conventional nozzles used for higher volume applications produce a significant volume of droplets smaller than 200 µm. Therefore, some potential for drift is evident with most spray applications. Spray directed above the trees is considered much more likely to be carried considerable distances. Proper adjustment of sprayer nozzles so that they hit the target trees is recommended for minimizing drift. Use of technology that directs spray more closely to the target trees may also aid in reducing off-target losses due to drift. Such technology may include the use of towers that direct spray laterally or downward onto the tree.

Salyani and Cromwell (1992) considered losses due to drift from airblast applications to citrus. Within the first 50 feet, they reported 50% greater ground deposition of the applied material in the high volume applications (544 gpa) vs. low volume (72 gpa). However the same study revealed a 22% loss due to drift past the target tree for low volume and 8% for high volume applications. Estimates of off-target deposition in apples ranged from a low of 30% using an application rate of 60 gpa to a high of 45% at 400 gpa.

The potential for surface water contamination in the IR area is not restricted to long-range drift of spray materials as is common in many agricultural areas. Most of these groves are situated on poorly drained soils with shallow hardpans. These groves are almost always bedded to facilitate drainage and contain networks of water furrows and relatively closely-spaced ditches. Off-target spray deposition to water in these ditches may present significant ecological risks. Likewise, materials deposited on the grove floor may be quickly carried into surface water through grove drainage.

Run-off of Spray from the Canopy

Environmental significance of spray material running off of tree surfaces is largely unknown. Efficient spray retention may reduce the total amount of pesticide needed to control a given pest, since materials not remaining on the target are not contributing to pest control. However, few studies have examined the fate of pesticides that run-off onto soil during the spray process vs. more gradual run-off from the canopy during weathering. Materials that are decomposed by ultraviolet radiation are likely to decline more rapidly on foliage than in the soil. It is also possible that heavy deposition at the canopy dripline from a high-volume spray may increase the probability of substantial spray entry into surface waters by exceeding the soil binding capacity, whereas more gradual and widely distributed weathering from leaves may prolong the soils ability to retain agrochemicals.

Cunningham and Harden (1998) investigated efficiency of application to mature citrus trees at 107 gpa, 214 gpa , 428 gpa , and 856 gpa. With the tracer material applied at a uniform concentration, total deposition was increased with greater spray volume, but efficiency of deposition declined. Compared at 1 mph sprayer speed, they estimated that 40% of the material was deposited on the canopy at 107 gpa, 34% at 214 gpa, 22% at 428 gpa, and 17% at 856 gpa (Table 1). The percentage of spray material falling from the canopy as runoff increased substantially when application rate exceeded 214 gpa. Five percent of material was lost as runoff at 107-214 gpa, 9% at 428 gpa, and 16% at 856 gpa.

Conclusions

Many factors influence spray deposition and distribution both on- and off- target. Further confounding the issue, surprisingly few experiments find significant differences when comparing aspects of spray technology such as ground velocity, nozzle arrangement, deposition, etc. The largest problem confronting such research is high variability for deposition, making it necessary to use large numbers of replicates to identify real differences.

Interactions between the factors influencing spray deposition, efficiency, and efficacy prevent conclusions of single cause-and-effect relationships for achieving good pesticide activity while minimizing environmental contamination and inefficiency. However, attention to interactions between a few factors appear likely to give growers a large measure of control over spraying while still permitting improved economic efficiencies and reduced potential for environmental contamination. This approach is explored and summarized in part III of this series (Stover et al., 2002b).

References

Albrigo, L.G., L.W. Timmer, K. Townsend, and H.W. Beck. 1997. Copper Fungicides-Residues for Disease Control and Potential for Spray Burn. Proc. Fla. State Hort. Soc. 110:67-70.

Brooks, R.F. 1969. Developing Pesticide Application Equipment for Citrus. Proc. First Int. Citrus Symposium 2:923-932.

Carman, G.E. and L.R. Jeppson. 1974. Low Volume Applications to Citrus Trees: Method for Evaluation of Spray Droplet Distributions. J. Econ. Ent. 67:397-402.

Citrus Administrative Committee. 2001. Utilization of Florida Citrus Fruit Reports 2000-2001 season. <http://www.citrusadministrativecommittee.org/bulletins/reports.html>.

Cromwell, R.P. 1975. Citrus Growers Guide to Air Spraying. University of Florida, IFAS Extension Circular 351.

Cunningham, G.P. and J. Harden. 1998. Reducing Spray Volumes Applied to Mature Citrus Trees. Crop Protection 17:289-292.

Florida Agricultural Statistics Service. 2001. Citrus Summary 1999-00. <http://www.nass.usda.gov/fl/rtoc0ci.htm>.

Fox, R.D., D.L. Reichard, R.D. Brazee, C.R. Krause and F.R. Hall. 1993. Downwind Residues from Spraying a Semi-Dwarf Apple Orchard. Trans. ASAE36:333-340.

Griffiths, J.T., Strearns, C.R. and Thomson, W.L. 1950. Possibilities for the Use Of Concentrated Sprays on Citrus in Florida. Proc. Fla. State Hort. Soc. 63:53-59.

King, J.R., P.J. Jutras and W.L. Thompson. 1959. Current Studies on the Efficiency of Equipment for the Application of Pesticides to Citrus Trees in Florida. Proc. Fla. State Hort. Soc. 72:16-21.

Salyani, M. 1995. Spray Deposition and Drift from Airblast Sprayers Used in Citrus Applications. Citrus Industry 76(1):35-39.

Salyani, M. and R.P. Cromwell. 1992. Spray Drift from Ground and Aerial Applications. Trans. ASAE35: 1113-1120.

Salyani, M. and J. D Whitney. 1991. Effect of Oscillators on Deposition Characteristics of an Airblast Sprayer. Trans. ASAE34:1618-1622.

Spray Drift Task Force. 1997. A Summary of Airblast Application Studies. <http://www.agdrift.com/Orchard_main.htm>

Stover, E. and J. Salvatore. 2002. Influence of Spray Volume, Ground Speed, and Sensor-Actuated Spray Manifolds on Pest Control in Fresh Grapefruit. Proc. Fl. Soc. Hort. Sci.

Stover, E., D. Scotto, and J. Salvatore. 2002a. Spray Applications to Citrus: Survey of Current Practices in the Indian River Area. IFAS Fact Sheet HS-127.

Stover, E., P. C. Wilson, D. Scotto and M. Salyani. 2002b. Spray Applications to Citrus: Opportunities and Limitations for More Effective, Efficient Spraying. IFAS Fact Sheet HS-130.

University of California. 1984. Integrated Pest Management for Citrus. Extension Publication 3303.

University of California. 1996. Citrus Spray Coverage. http://axp.ipm.ucdavis.edu/PMG/r107300911.html

Whitney, J. and M. Salyani. 1991. Deposition Characteristics of Two Air-Carrier Sprayers in Citrus Trees. Trans. ASAE 34:47-50.

Zhu, H., D. L. Reichard, R. D. Fox, R. D. Brazee and H. E. Ozkan. 1994. Simulation of Drift of Discrete Sizes of Water Droplets from Field Sprayers. Trans. ASAE 37:1401-1407.

Table 1. Estimates of spray deposition and loss following commercial spray to mature Ellendale trees in Australia (from Cunningham and Harden, 1998). All applications compared at 1 mph, VMD of 136-138 µm and identical tracer concentration. Unaccounted spray is calculated and would include material on trunk and branches, fallout onto orchard middles, and drift. Within a column, numbers followed by the same letter are not significantly different at p=0.05.

Application rate (gallons per acre)	Leaf spray recovery (%)	Run-off from canopy (%)	Unaccounted spray material (%)
107	39.8 a	4.7 c	56
214	34.5 ab	5.4 c	60
428	21.8 cd	9.0 b	69
856	16.9 d	16.2 a	67

Table 2. Estimating maximum tractor speed for Complete Air Displacement (miles/hour). Note that these values are only accurate when manifold is adjacent to tree canopy. Also high tractor speed can affectively reduce sprayer wind velocity.

	Sprayer CFM from both sides of the manifold						
	30,000	35,000	40,000	45,000	50,000	55,000	60,000
Tree Size (ft in height X ft across row)							
12 X 12	2.4	2.8	3.2	3.6	3.9	4.3	4.7
12 X 14	2.0	2.4	2.7	3.0	3.4	3.7	4.1
14 X 14	1.7	2.0	2.3	2.6	2.9	3.2	3.5
14 X 16	1.5	1.8	2.0	2.3	2.5	2.8	3.0
16 X 16	1.3	1.6	1.8	2.0	2.2	2.4	2.7
16 X 18	1.2	1.4	1.6	1.8	2.0	2.2	2.4
18 X 18	1.1	1.2	1.4	1.6	1.8	1.9	2.1
18 X 20	0.9	1.1	1.3	1.4	1.6	1.7	1.9
20 X 20	0.9	1.0	1.1	1.3	1.4	1.6	1.7
20 X 24	0.7	0.8	0.9	1.1	1.2	1.3	1.4